Collective Intelligence and Three Aspects of Planning in Organizations: A NASA Example

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Collective Intelligence and Planning.

We construe "collective intelligence" (CI) in terms of a) activity and b) outcome, rather than in terms of the supporting technology: collective intelligence is a) the generation, apprehension, and use of distributed information through collaborative processes and b) the knowledge or products resulting from such activity.

Our perspective on collective intelligence concerns planning within an organization. By "planning" — the process, we mean identifying events and scheduling them in time, with the intent to guide or anticipate future actions. By plan—the product, we mean an externally represented specification of a (partially) ordered set of activities. In organizations, planning depends on collective intelligence and plans in turn provide input to collective intelligence. While study of planning by people and computers has a long and varied tradition (e.g. Wilensky, 1983; Fikes & Nilsson, 1971), designing effective tools to support complex planning by groups of people remains a very difficult problem (Butler, Zhang, Esposito, Bahrami, Hebron, & Kieras, 2007).

Our core example comes from the domain of planning by the ADCO controller group (Attitude Determination and Control), which is part of NASA's mission control of the International Space Station. This group plans the detailed sequence of activities needed to position the ISS, while collaborating across groups to ensure the appropriateness of the planned activities in the wider context of the ISS mission. In addition, we are informed by NASA Ames research and application development for several other planning domains, including planning for Mars Rover scientific activity and scheduling activities in a bed rest facility (McCurdy, Luowise, Marquez, & Li, 2009).

Temporal Structure of Planning

Planning/Scheduling is organized around temporal structure, and its temporal structure is distinctive and complex. Further, from a technology point of view, CI tools that work effectively for domains not organized around temporal structure (in many examples of CI from bookmarking to wiki-writing) may be unsatisfactory for domains primarily structured by time. Nevertheless, planning typically is and ought to be a collective intelligence activity. Indeed, the need for complex planning and scheduling primarily arises for complex sociotechnological systems. Such systems

demand participation of multiple, coordinated players. The needed participation will vary in how tightly coupled both the timing and the intentions of the players need to be, but collectively distributing and consolidating information is critical.

Planning has three important temporal profiles, which we label future-focused, present-focused, and past-focused. Within each of these, the relevant activity can vary in the extent and nature of collaboration, that is, in the organization of collaborative intelligence. Recognition of these three profiles is important because each is often analyzed and supported in relative isolation from the others, yet work typically involves switching among and coordinating these temporal profiles.

Future-focused profile. When building a plan, users are focused on the future. The activity of planning, distinct from the planned activity, is itself often a complex, and collaborative, process. In collaborative planning, decision-making by one individual or group depends on information from other groups or individuals and in turn information from the first group is needed as input by others. There may be a broad "upstream-downstream" direction of dependencies, and indeed procedures are developed to try to regularize and reduce interdependencies in information flow. Nevertheless, there frequently is considerable interactivity in making the decisions that are reified in the plan. Interaction may be formalized in part, as in approval protocols, but it also flows via informal requests and offers. Informal communications typically enable the success of formal communications. A future-focused profile of planning involves *collective* intelligence to the extent that construction of the plan is collaborative and draws on a variety of information sources.

Present-focused profile. When executing a plan, users are focused on the present. A plan is successful to the degree it supports execution; planning in sociotechnical systems is driven by the need to coordinate execution of complex tasks. Fluent and accurate execution of sufficiently complex tasks is only possible when information has been gathered, understood, and applied in advance, so that the bulk of decisions have been "precompiled" in a plan, leaving the smallest possible set to be addressed "in the heat of action." Execution often requires coordinated action by multiple individuals in multiple groups. A successful collaborative plan must support the participating groups in carrying out the actions within their responsibility and it must ensure that the activities across contributing groups are appropriately coordinated. A present-focused profile of planning involves *collective* intelligence to the extent that execution of the planned-for activity is collaborative.

Past-focused profile. After the action, a plan becomes history. It provides a record of intensions and, if updated or revised with what events actually took place, a historical record. When analyzing enacted plans, users are focused on the past. A record of actual events, intended events, and their comparison is very powerful information. Old plans can be used as templates to efficiently generate similar new plans and they can provide the information to identify past problems or inefficiencies and design improved plans for the future. However, it is often very difficult for an organization to make effective use of enacted plans to guide

subsequent iterations of planning and acting. A past-focused profile of planning involves *collective* intelligence to the extent that reuse and analysis of old plans is collaborative.

An Example: Planning in the ADCO mission control group

We use these three temporal profiles to summarize the planning activities in ADCO, and describe some of the challenges in designing support for the activities. Our focus has been on the future-focused process of planning, but this prompted both observations and questions about the present- and past-focus. In addition, we mention contrasting cases of planning to point out the variety of planning needs.

Future-focus. In ADCO, planning is done by the same group of individuals as those who will be executing the plan. An ADCO plan gets high level input from the mission planners. ADCO and Russian counterparts then plan the details of the required manuovers. Plans are passed back and forth between ADCO and Russian groups through a series of formal approval steps. ADCO distributes its developing plan to other disciplines, such as those responsible for power, who need to know the orientation of the ISS for their own planning. In turn, the orientations specified in the developing plan may be adjusted if they unduly restrict the ability of other groups to meet their own requirements.

Planning is complicated by the nested structure of activity and of plans. Activities defined by higher-level goals and running over longer time spans typically have instrumental, shorter activities nested within them. Planning higher level activities typically precedes specification of lower level activities intended to accomplish the higher level unit, and often is carried out by different groups or individuals than those planning the lower, more tactical actions. For ADCO the planning process itself is strictly scheduled, with 30-day, 7-day, 3-day, and 1-day plan reviews and increasing demand that all details are specified and unchanged as the time of execution approaches. Plan propagation is awkward, as ADCO enters the same information in at least 3 products. Further, ADCO cannot take a high level plan developed for mission level planning as input and use this to seed their own more detailed plan development.

Present-focus. During mission execution many Mission Control groups work together to monitor and control the subsystems of the space station. In addition, coordination with Russian counterparts is required. The technical and social complexity requires both that many tasks are done in advance (either directly by humans or off-loaded into computerized procedures). For novel or risky activities, ADCO also has backup plans, in which solutions applicable to potential problem situations are precomputed and may actually be uploaded and available for use on the ISS. During execution, the ADCO operator in control is co-located with the controlling operators from other mission control disciplines. There is important informal communication among disciplines, such as alerting other operators that an anticipated and unproblematic warning message will be appearing shortly. In other domains, such as facility scheduling, real-time execution of the plan (e.g. putting a

subject in the correct room) may be relatively simple, and require relatively little coordination.

For ADCO, the same collection of international partners and disciplines within Mission Control are collaboratively involved in both planning and execution. In contrast, Mars Rover activities are planned by one group of scientists, but a different, engineering group monitors the Rover's activities, which are designed to be executed autonomously.

Past-focus. ADCO heavily reuses old plans, to act as templates for new plans. There are at least two types of impact that reuse has. Reuse increases efficiency of planning, because adapting a prior plan typically is a small part of the effort of creating a new one. This is clearly true at the level of the mechanical construction of the plan, as this requires tedious and error-vulnerable data entry. Reuse is also related to the conservative planning stance of ADCO. ADCO planners state that they are primarily concerned with getting a sufficiently good plan, that is correctly communicated and implemented, rather than building the best plan. This is encouraged by and encourages the reuse of old plans: not only does it reduce effort at the mechanical level, but it is believed to reduce risk at the analytical level. Doing something very similar to what has been done previously is likely to be safer. While this approach is guided by official flight rules about what actions are sanctioned, it also is expressed in informal processes.

ADCO updates the active plan to show how it was modified in execution and saves an "as-flown" plan. ADCO operators recognize the value of these for identifying places where procedures might change or where the situation was not as anticipated; we did not see or investigate when or by whom retrospective analysis is systematically done. Retrospective analysis of plans remains an interesting open issue. For high risk, safety-critical domains, this retrospective aspect of planning may be where collective intelligence, distributed collaboration, and social networking technologies may be most valuable.

<u>Support for planning.</u>

For many complex sociotechnical systems, planning seems to require explicit coordination; certainly, in executing a plan the activities of different actors must be tightly coupled. However, distributing the needed planning information can be very burdensome and error prone, because different groups need different collections of information, updated or kept current on different time cycles. Further, the information needed to form successful plans is often highly distributed, and while feedback about the success of prior plans may exist, it may not be available to those in a position of using this to improve plans or to detect and resolve other problems in the system (Weick, 1995).

Tools to support various aspects of planning have been developed, and can provide a huge benefit to the individuals working on that aspect. To be tractable, most solutions address a quite bounded slice of work, isolating it from the larger context.

Prospective planning takes place over multiple, nested cycles of decision making. This builds a plan that specifies activities of different granularity. "Subplans" may specify multiple parallel activities by different groups and individuals, as well as sequential, nested actions by a single actor. Planning produces valuable, sharable, external, representations: in addition to prospective use, plans support retrospective assessment and also action in the present. Viewing planning in a larger context – both temporal and organizational -- enables noticing what one does not know and generating more systemic and effective solutions.

Viewing a problem as one of collective intelligence invites thinking about the larger organizational context. Many approaches to supporting collective intelligence do not support execution of highly contingent actions, distributed across many players, and hence provide incomplete support for planning. However, CI technology maybe helpful in managing the processes of gathering information for decision making in planning and of distributing plan information to various actors, needed on various time cycles.

References

Butler, K.E., Zhang, J., Esposito, C., Bahrami, A., Hebron,R., & Kieras, D. (2007). *Work-Centered Design: A Case Study of a Mixed-Initiative Scheduler.* CHI 2007 Proceedings, New York :ACM. Pp 747-756.

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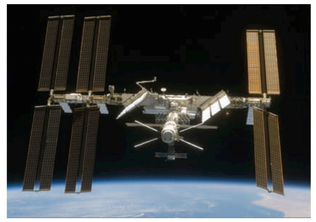

PLANNING

Planning&Scheduling is organized around temporal structure. Planning typically is a collective or collaborative activity. Indeed, the need for complex planning primarily arises for complex sociotechnological systems, which demand participation of multiple, coordinated players. The participation varies in how tightly coupled both the timing and the intentions of the players need to be, but collectively distributing and consolidating information is critical.

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High level plan.
Circle indicates one planned docking.

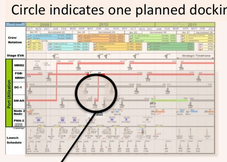
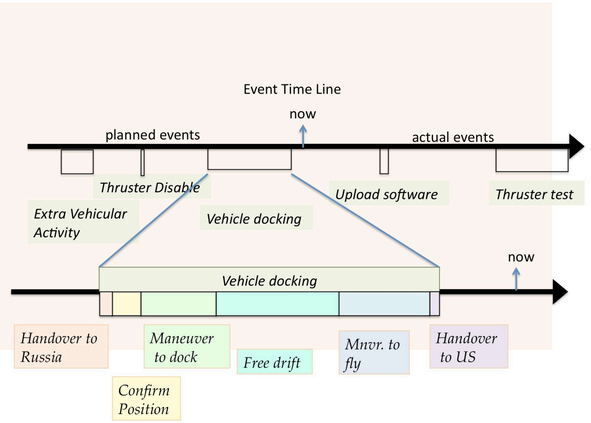


Illustration of Information expansion
from an early, high level plan to the plan used in execution.
The initial plan component specified as dock vehicle V, Port P, and time, expands to 16X97 cells in a spread sheet.

Detailed, execution plan. Information has expanded to cells illustrated here.



Plan Structure

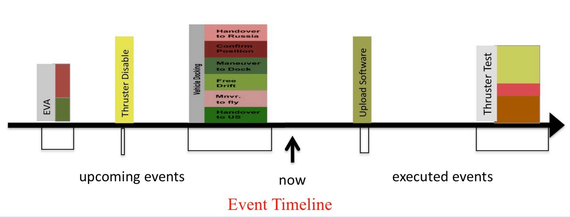
A plan represents a partially ordered temporal sequence of activities for accomplishing a goal. Plans are typically hierarchical in structure, with higher level missions decomposable into constituent tasks. Plans vary in specificity and in commitment. (Plans may include branching and planning for contingencies.)

3 Temporal Profiles

Planning/Scheduling is organized around temporal structure.
Plans and planning involve three temporal profiles.
Present- Focused: Plans are developed to guide the execution of action-in-the-moment.
Future-Focused: During plan development future goals, conditions, and actions are envisioned and specified.
Past-Focused: After execution, the plan remains as a record of the past, to allow comparison of intended and actual actions and outcomes.

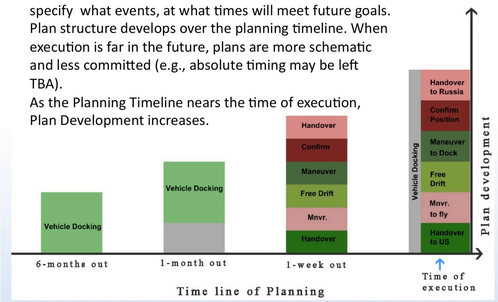
Present-Focused Profile

A plan is intended to guide execution of the planned activities. **Actors use plans to engage with the present.** The NOW, the execution time, passes through the planned sequence of events.



Future-Focused Profile

Planners use plans to engage with the future, trying to specify what events, at what times will meet future goals. Plan structure develops over the planning timeline. When execution is far in the future, plans are more schematic and less committed (e.g., absolute timing may be left TBA).
As the Planning Timeline nears the time of execution, Plan Development increases.

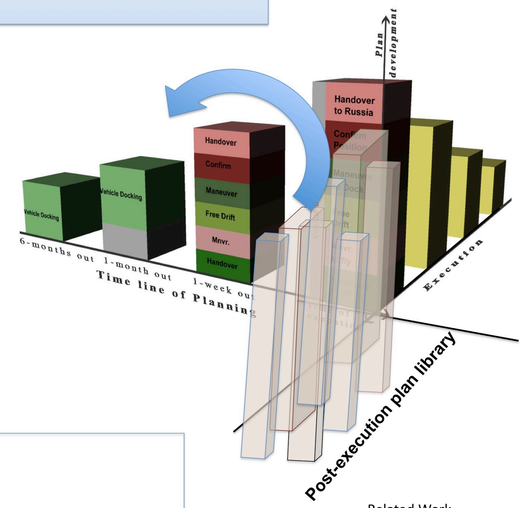


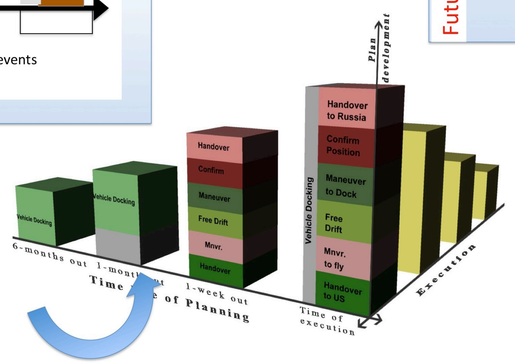
Planning Timeline

Past-Focused Profile

Analysts use plans to engage with the past. The fully developed plan persists and may be annotated where intended and enacted events diverge.

The collection of highly developed, post-execution plans provides a history library.





Collective/Collaborative Intelligence

In complex sociotechnological systems–including the ADCO Mission Controllers--collaboration in execution typically requires tightly coupled intentions and timing. Component actions and who does them are typically preplanned; specifying the timing of actions enables coordination and reduces need for real-time monitoring of other's actions.
All possible is done to minimize the need for novel sense-making when executing difficult tasks. Monitoring, however, may be distributed, e.g. all groups in Mission Control may track any warning or error message.

Present-Focused

Collective/Collaborative Intelligence

Planning requires extensive interaction within and across work groups.
ADCO: Data and systems are 'stovepiped'. Data exchange is very structured, but eased by availability of informal communication with co-located work. Cross-sitegroups/ cross-institution informal communication [between Russian and US attitude controllers] is quite limited but valued.
Work practices are based heavily on explicit policies. Each work group develops and owns its own tools and data.

Future-Focused

Collective/Collaborative Intelligence

Plans of completed actions are a rich data source
-as prior cases or templates in planning future similar events; conservative reuse of successful plans is particularly important in safety-critical domains where all resources to reduce risk are high value; and
-as record of mismatch between expected and actual events; this can guide evolution of policy and practice.
Collective reflection on past practice, through the records left in plans, could be very valuable. We don't know a lot about ADCO's practice but:
-Work practices currently seem unsystematic and underuse this information.
-Within ADCO, members spend much, self-structured time reviewing plans in development, but apparently little "learning from the past" in this way.
-Few relevant tools are available.
When and for whom is this library of fully elaborated plans useful?

Past-Focused Profile

Related Work

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